

Fault Tolerant Crew Cabin Systems Controller for Gaganyaan

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Abstract—Gaganyaan program represents India's inaugural endeavour to establish human presence in Earth's Low Earth Orbit. The Orbital module is designed to accommodate astronauts and various electronic systems like environment monitoring systems, crew display systems, cabin lighting systems, camera systems, communication systems, audio-video processing systems, etc. Crew Cabin Systems Controller (CCSC) Module is an integral part of Audio Video Processing System that serves as a crucial intermediary between on-board electronics and Mission Computers for Tele-Command & Telemetry information exchange. This paper offers a comprehensive exploration of the design of Fault Tolerant Crew Cabin Systems Controller for the Gaganyaan mission.

Keywords—Crew Cabin System Controller (CCSC), Mission Computer (MC), RISC (Reduced Instruction Set Computer), Electronic Power Conditioner (EPC), Field Programmable Gate Array (FPGA), Tele-Command (TC), Telemetry (TM).

I. INTRODUCTION

India's highly anticipated and cutting-edge mission, 'Gaganyaan', is poised to launch the Orbital module housing Indian astronauts aboard Human Rated Launch Vehicle into low Earth orbit. During its 5-7 day mission, the spacecraft will not only demonstrate India's prowess in the science and technology sector but also serve as a testament to its capabilities in space exploration.

The Orbital Module boasts state-of-the-art avionics systems designed with human safety as the paramount concern. Within the Crew Module, a habitable environment akin to Earth is meticulously crafted, housing essential interfaces, life support systems, avionics, and other human-centric necessities for the crew's well-being.

Communication between the crew and ground control is facilitated through on-board Mission Computers (MC), which, in turn, interface with other on-board systems via Crew Cabin Systems Controller (CCSC). CCSC serves as the central entity responsible for managing Tele-Command (TC) distribution and Telemetry (TM) monitoring of various on-board systems. Fault tolerance & dual modular redundancy are ensured with the deployment of two hot-redundant CCSC units to safeguard against system failures. Three independent MIL-STD-1553 links with complete redundancy in hardware & software chains is implemented to communicate with three independent MCs. Its robust software architecture is meticulously designed to handle TCs from multiple Mission Computers, ensuring efficient bus arbitration and response mechanisms that poses a significant design challenge for CCSC, as elaborated in subsequent sections of this paper.

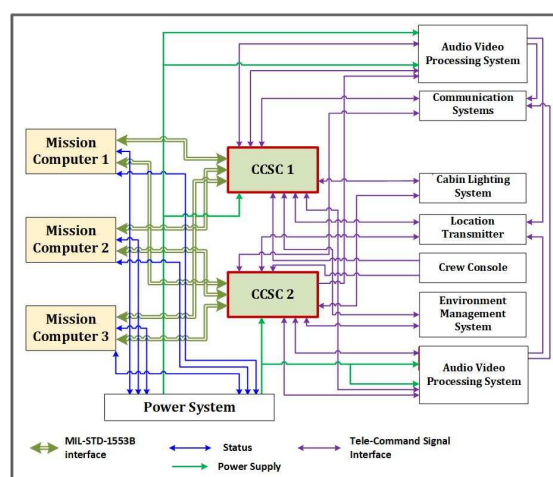


Fig. 1: CCSC Interface with Mission Computer and On-board systems

Crew Cabin Systems Controller serves as a sophisticated embedded control system, seamlessly integrating state-of-the-art hardware and embedded software. CCSC hardware utilises all Space-qualified components to offer highest reliability in space environment. Hardware level cross patching is implemented between two CCSC units and interfacing subsystems to ensure seamless connectivity. Intricate interconnections between three MCs, two CCSCs, and multiple other crew cabin systems is illustrated in Fig. 1, highlighting the complex yet reliable architecture of the Gaganyaan mission.

II. CCSC SYSTEM REQUIREMENTS

Crew Cabin Systems Controller addresses following major system requirements:

- Manage power On-Off controls and power TM acquisition for interfacing Crew Cabin systems.
- Coordinate Serial TC generation and TM Reception Communication systems.
- Collect Analog & Thermistor TM from various interfacing systems to monitor temperature.
- Establish interface with three MCs for MIL-STD-1553B TC-TM communication.
- Implement bus arbitration & time-out qualifier logic for fault tolerant seamless TC-TM communication over three MIL-STD-1553 buses with three MCs concurrently.
- Facilitate two-way Serial Communication with Audio Video Processing Unit via 3-wire serial interface for Crew Cabin Display Parameter information exchange.

III. CCSC HARDWARE OVERVIEW

Gaganyaan Crew Cabin Systems Controller hardware design is centric to Microchip RTG4 FPGA device to execute specified functionalities. RTG4 FPGA provides an advantage of low power, live at power on and re-programmability even at the advanced stages of package integration compared to SRAM and Antifuse based FPGAs. Furthermore, choice of soft processor core over hardware chip was made for miniaturization in terms of Size, Weight and Power (SWaP). CCSC hardware accommodates 16 Mb Non-Volatile Magneto-Resistive RAM (MRAM) device for storing on-board application code based on the RISC-V processor, accessed by RTG4 FPGA for execution. Powered by +5.0 Volts input supply from the Electronic Power Conditioner (EPC) subsystem, the CCSC hardware employs on-board LDO & POL devices to generate additional necessary voltage supplies. It incorporates three MIL-STD-1553 Bus Interface devices to establish communication with all three Mission

Computers via individual MIL-STD-1553 links. If any of the MIL-STD-1553 link fails, communication is not hampered through smooth switchover from one link to another.

48-MHz on-board clock oscillator device serves as the master clock source for CCSC hardware. The hardware integrates various buffer and transceiver ICs to accommodate different interface types, such as Complementary Metal Oxide Semiconductor (CMOS), RS-422, RS-485, Low Voltage Differential Standard (LVDS), etcetera, with various subsystems.

For receiving temperature telemetries from other subsystems, CCSC hardware includes provisions for on-board ADC devices. Additionally, it houses an on-board Watch Dog Timer device to serve as a fault detection and recovery feature mechanism. Developmental Model (DVM) hardware photograph and Block level detail of CCSC hardware are shown in Fig. 2 & Fig. 3 respectively.



Fig. 2: CCSC Hardware

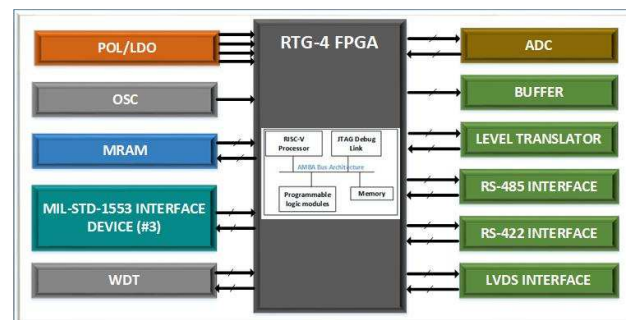


Fig. 3: CCSC Hardware Block Diagram

IV. CCSC SOFTWARE OVERVIEW

Programmable functionality of CCSC hardware is implemented within the Flash-based RTG4 FPGA device. 32-bit LEON & RISC-V soft processor cores were explored for implementation out of which RISC-V soft

core with On-chip Floating Point Unit (FPU) architecture [1]- [3] was chosen as it is an optimised design for RTG4 FPGA in terms of resource utilization. Various functional logic modules are interfaced with the processor using on-chip AMBA SoC Bus [4] such as in-house developed MIL-STD-1553 Remote Terminal Intellectual Property core [5], serial interface modules, Modem serial communication Universal Asynchronous Receiver Transmitter (UART) module [6], Programmable Pulse Generator Module, etc. to interface with various crew cabin systems.

Application code for RISC-V Processor is stored in the on-board MRAM device [7], while other programmable logic components reside in the RTG4 FPGA's on-chip Flash memory. Upon power application to the hardware, CCSC hardware promptly delivers the desired functionality.

CCSC RISC-V Processor Application Software is written in bare-metal C-language. CCSC receives TCs & configuration data and transmits TM data from/to Mission computers through three hot redundant MIL-STD-1553 links. Mission Computers simultaneously send TC information to the CCSC system via three individual MIL-STD-1553 links.

Bus arbitration logic, responsible for validation and decision-making based on received commands from Mission Computers, is implemented in the processor application code. When a TC is received from any one of the MIL-STD-1553 links, the arbitration logic verifies the validity of received commands and triggers the time-out qualifier logic to check the command in the other two links. If identical commands are received in all three MIL-STD-1553 links, the TC from the other two links will be discarded, and the software functionality will be executed once based on the received TC.

A block-level architectural detail of the RTG4 FPGA design is depicted in Fig. 4.

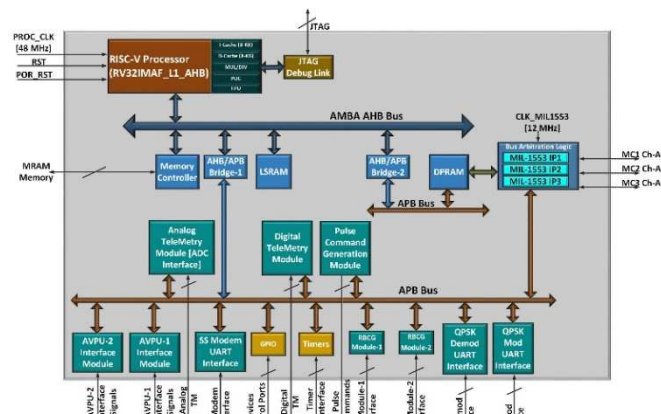


Fig.4: RTG4 FPGA Design Architecture

V. HUMAN RATING CERTIFICATION

Human Rating Design aspects [8]-[12] are considered for CCSC hardware design as well as software implementation as it is the prime requirement for a human centric mission. Fault Tree Analysis, Event Tree Analysis, Failure Mode Effect & Criticality Analysis, Route to Certification, Preliminary Hazard Analysis & Software Subsystem Hazard Analysis etcetera will be carried out to ensure human rated system design. Software design has been carried out following guidelines derived from ISRO Software Safety Standard (ISSS) and other Human Rating Certification guidelines. Human rating certification clearance will be acquired before actual integration of the hardware.

VI. ELECTRONIC GROUND CHECKOUT SYSTEM

A dedicated Ground Checkout Unit has been developed to evaluate the comprehensive functionality of CCSC hardware. To emulate Mission Computer functionality, a user-friendly Graphical User Interface (GUI) has been developed. This GUI software is hosted on an Industrial PC and facilitates communication with the CCSC hardware via the MIL-STD-1553 interface. Furthermore, a Mission Computer Simulator has been designed to generate various TCs and TM exchanged over the MIL-STD-1553 bus with the On-board MCs. USB/cPCI based cards are utilised to realise the MIL-STD-1553 interface link with CCSC.

CCSC Subsystem operates three concurrently active 1553 links, each interfacing individually with an MC. MC Simulator GUI is developed using Microsoft Visual Studio and implemented in the C# language. This development harnesses the Bus-1553 API, which supports C#, enabling the GUI to effectively manage protocol data over the MIL-STD-1553 lines. Snapshot of the Graphical User Interface and Mission Computer Simulator test setup block level diagram are provided in Fig. 5 and Fig. 6, respectively.

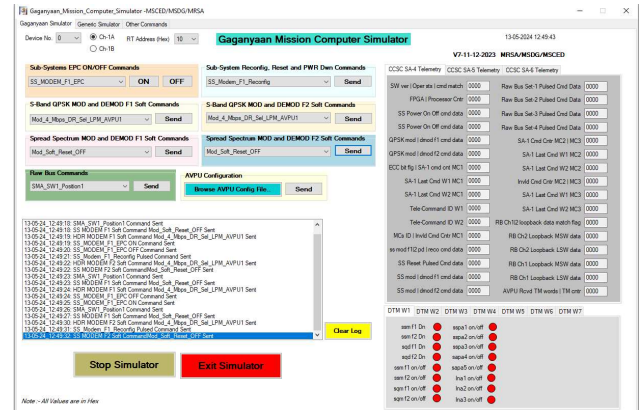


Fig. 5: Mission Computer Simulator GUI

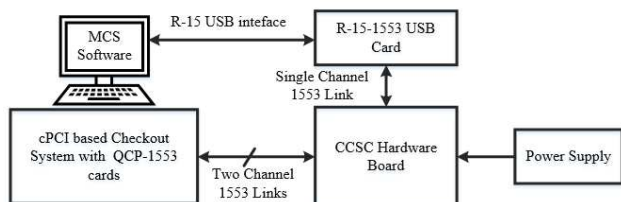


Fig. 6: Electronics Ground Checkout System

VII. HARDWARE TEST RESULTS

The developmental model of the CCSC hardware has been thoroughly tested & functionally verified in an ambient environment. The hardware has been evaluated in an integrated configuration with various On-board subsystems and MC Simulator software. The functionality was validated by measuring width of pulse signals and data of serial streams, as well as monitoring TM on the MC Simulator software. Additionally, UART interface with Modem was confirmed by receiving serial data through the computer. CCSC FPGA design resource utilisation is shown in Table I. The design incorporates functionalities of Audio Video Processing Unit (AVPU) high speed serial interface, Modem UART interface and other programmable logic modules catering to CCSC functional requirements.

TABLE I: CCSC FPGA Resource Utilization

Type	Used	Total	%
4LUT	73342	151824	48.30
D-Flip Flop	56439	151824	37.17
RAM64x18	17	210	8.09
RAM1Kx18	120	209	57.41

CCSC Hardware has been tested exhaustively with Mission computer Simulator software and AVPU electronics as shown in Fig. 7. Various TC-TM test cases have been verified to measure the command execution and housekeeping TM update latency on the hardware.

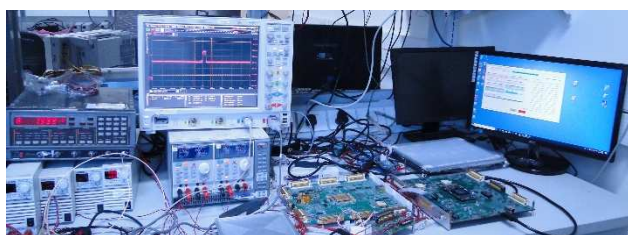


Fig. 7: CCSC Hardware Interface Test Setup

VIII. CONCLUSION

Crew Cabin Systems Controller subsystem serves as the crucial control and information link between three Mission Computers and numerous cabin systems on-board. Its responsibilities encompass overseeing the overall control, configuration, and status monitoring of the various cabin systems. TM and TC data are exchanged exclusively

between two hot redundant Space-qualified CCSC hardware and multiple MCs via individual MIL-STD-1553 buses that provides a reliable and fault tolerant architecture. To handle the diverse range of TM types, including digital, analog, and temperature readings, as well as CMOS and Raw Bus TCs, the CCSC hardware is equipped with multiple interfaces.

Upon receiving TCs from Mission Computers, the CCSC system executes power on/off commands for various on-board subsystems. Both the CCSC systems collaborate closely with multiple Mission Computer systems to effectively manage and control the cabin systems during mission operations. Both CCSCs connect with all interfacing crew cabin systems. Hence, even in the case of one system failure, the other CCSC takes over smoothly without compromising in any functionality.

Throughout the design and software implementation of the CCSC hardware, careful attention has been paid to all human-rating design considerations, ensuring the system's reliability and safety meeting rigorous standards.

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